Tau Neutrinos in the Auger Observatory : A New Window to UHECR Sources.

X. Bertou, P. Billoir, O. Deligny, C. Lachaud, A. Letessier-Selvon [a]

[a]L.P.N.H.E. Paris VI-VII, 4 place Jussieu, 75252 Paris, France

The cosmic ray spectrum has been shown to extend well beyond 10^{20}eV. With nearly 20 events observed in the last 40 years, it is now established that particles are accelerated or produced in the universe with energies near 10^{21}eV at the production site. In all production models neutrinos and photons are part of the cosmic ray flux. In acceleration models (bottom-up models), they are produced as secondaries of the possible interactions of the accelerated charged particle; in direct production models (top-down models) they are a dominant fraction of the decay chain. In addition, hadrons above the GZK threshold energy will also produce, along their path in the Universe, neutrinos and photons as secondaries of the pion photo-production processes. Therefore, photons and neutrinos are very distinctive signatures of the nature and distribution of the potential sources of ultra high energy cosmic rays. In the following we describe the tau neutrino detection and identification capabilities of the Auger observatory. We show that in the range $3 \times 10^{17} - 3 \times 10^{20}$ eV the Auger effective apperture reaches a few tenths of $km^2.sr$, making the observatory sensitive to fluxes as low as a few tau neutrinos per $km^2.sr.year$. In the hypothesis of $\nu_\mu \rightarrow \nu_\tau$ oscillations with full mixing, this sensitivity allows to a probe of the GZK cutoff as well as providing model independent constraints on the mechanisms of production of ultra high energy cosmic rays.

1. Introduction

The origin of Ultra High Energy Cosmic Rays observed on Earth is a long lasting mystery[1–4]. While the cosmic ray spectrum is now shown[5,6] to extend beyond 10^{20}eV, mechanisms producing or accelerating particles with energies near or above 10^{21}eV are still uncertain.

Only very powerful astrophysical objects can, in principle, produce these energies through conventional acceleration. However the environment of the source itself generally prevents the accelerated particle to escape the site without severe energy losses, making such scenarios unlikely to explain the origin of UHECR.

Alternative hypotheses involving new physics such as collapse of Topological Defects (TD) or decay of Super Massive Relic Particles (SMRP) are well suited to produce particles above 10^{20}eV but they still lack a proof of existence. Moreover such models may reproduce the power law spectrum observed for the cosmic rays only at the condition that the decaying particle is much heavier than 10^{20}eV.

Transport from the source to Earth is also an issue. At those extreme energies the Cosmic Microwave Background Radiation makes the Universe essentially opaque to protons, nuclei and photons which suffer energy losses from pion photo-production, photo-disintegration or pair production. These processes led Greisen, Zatsepin and Kuzmin[7] to predict a spectral cutoff around 5×10^{19}eV, the GZK cutoff. The available data, although still very scarce, do not support the existence of such a cutoff. Therefore the sources are either close by and locally more dense for the cutoff not to show, or new physics modifies the expected energy losses of UHECR against the CMB photons.

In this framework neutrino are an invaluable probe of the nature and the distribution of the potential sources. Essentially unaffected on their journey to Earth they may allow us to disentangle the source characteristics from the propagation distortions. In the following we will briefly describe the Auger observatory and show how ν_τ are expected to interact and propagate in the Earth crust and be detected in Auger as low altitude and

almost perfectly horizontal showers. In the framework of full $\nu_\mu \leftrightarrow \nu_\tau$ mixing we will then evaluate our sensitivity to potential neutrinos sources and in particular to the low but almost certain flux of GZK neutrinos.

2. Neutrino detection with the Auger detector

Large area ground based detectors do not observe the incident cosmic rays directly but the Extensive Air Showers (EAS), a very large cascade of particles, that they generate in the atmosphere. All experiments aim to measure, as accurately as possible, the direction of the primary cosmic ray, its energy and its nature. There are two major techniques used. One is to build a ground array of sensors spread over a large area, to sample the EAS particle densities on the ground. The other consists in studying the longitudinal development of the EAS by detecting the fluorescence light emitted by the nitrogen molecules which are excited by the EAS secondaries.

The Auger Observatories[1] [8] combine both techniques. The detector is designed to be fully efficient for showers above 10 EeV (1 EeV$\equiv 10^{18} eV$), with a duty-cycle of 100% for the ground array, and 10 to 15% for the fluorescence telescope. The 1600 stations of the ground array are cylindrical Čerenkov tanks of 10 m^2 surface and 1.2 m height filled with filtered water; they are spaced by 1.5 km into a triangular grid. The construction started in the fall of 2000 in Argentina. Once completed in 2006, the observatories will be covering one site in each hemisphere. Their surface, 3000 km^2 each, will provide high statistics. With a total aperture of more than 14000 km^{2}sr, the Auger Observatories should detect every year of the order of 10000 events above 10 EeV and 100 above 100 EeV.

Previous studies on UHE neutrino interaction in the atmosphere and observation with Auger were reported in [9,10]. The idea of detecting ν_τ interactions through the shower induced by the τ decays in the atmosphere was presented in [11,12].

In the following we will describe the specificity of the tau neutrinos interaction and propagation, together with the possibility to detect the tau decay above the Auger ground array.

2.1. Relevent properties of tau neutrinos

Standard acceleration processes in astrophysical objects hardly produce any ν_τ. In top-down models there is a full equivalence between all flavors at the beginning of the decay chain but this symmetry breaks down at the end of the fragmentation process where the pions which yield most of the expected neutrino flux are produced.

This situation changes radically in the case of $\nu_\mu \leftrightarrow \nu_\tau$ oscillations with full mixing, a hypothesis that seems to be supported by the atmospheric neutrino data and the K2K experiment [13]. In such a case the $\nu_e : \nu_\mu : \nu_\tau$ flux ratios originally of $1 : 2 : 0$ evolves towards $1 : 1 : 1$ for a very wide range in δm^2 (given the very large distance between the source and the Earth). Half of the ν_μ gets converted into ν_τ and all flavors are equally represented in the cosmic ray fluxes.

Unlike electrons which do not escape from the rocks or muons that do not produce any visible signal in the atmosphere[2], taus, produced in the mountains or in the ground around the Auger array, can escape even from deep inside the rock and produce a clear signal if they decay above the detector.

The geometrical configuration that must be met to produce a visible signal is rather severe. Neutrinos must be almost perfectly horizontal (within 5 deg.). Therefore less than 10% of the solid angle is available while the neutrino energy and the distance between the interaction and the detector must match to have a good chance of observing the tau decay. We will show in the following that indeed these criteria can be met and that most of the detectable signal (90%) comes from upward going ν_τ where the interactions occur in the ground all around the array and only 10% from downward going ν_τ coming from interactions in the mountains surrounding the array.

[1] Named after the French physicist Pierre Auger.

[2] The electro-magnetic halo that surrounds very high energy muons does not spread enough in space to produce a detectable signal in an array of detectors separated by 1.5 km.

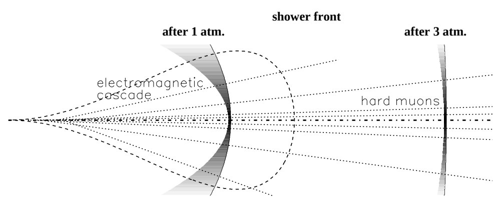

Figure 1. Horizontal shower development.

2.2. Deep showers

The UHE neutrinos may be detected and distinguished from ordinary hadrons by the shape of the horizontal EAS they produce. Ordinary hadrons interact at the top of the atmosphere. At large zenith angles (above 80 deg.) the distance from the shower maximum to the ground becomes larger than 100 km. At ground level the electromagnetic part of the shower is totally extinguished (more than 6 equivalent vertical atmosphere were gone through) and only high energy muon survive. In addition, the shower front is very flat (radius larger than 100 km) and the particles time spread is very narrow (less than 50 ns).

Unlike hadrons, neutrinos may interact deeply in the atmosphere and can initiate a shower in the volume of air immediately above the detector. This shower will appear as a "normal" one - although horizontal -, with a curved front (radius of curvature of a few km), a large electromagnetic component, and with particles well spread over time (over a few microseconds) [see Figure 1]. With such important differences, and if the fluxes are high enough, neutrinos can be detected and identified.

Showers produced from a τ decay have the same characteristics as neutrino ones. We simulated them with the AIRES program [14]. A special mode, allowing the simultaneous injection at a given point of several particles with any direction was used. The development of the cascades in air, with a thinning energy threshold of $E_{thin} = 10^{-7}\,E_\tau$, produced a set of weighted "ground particles", which provides a good description of the densities expected at each Čerenkov tank. It is important to mention that up going particles were allowed throughout the cascade, as long as they remained inside a very large volume surrounding the shower maximum, while particles hitting the ground were not followed further.

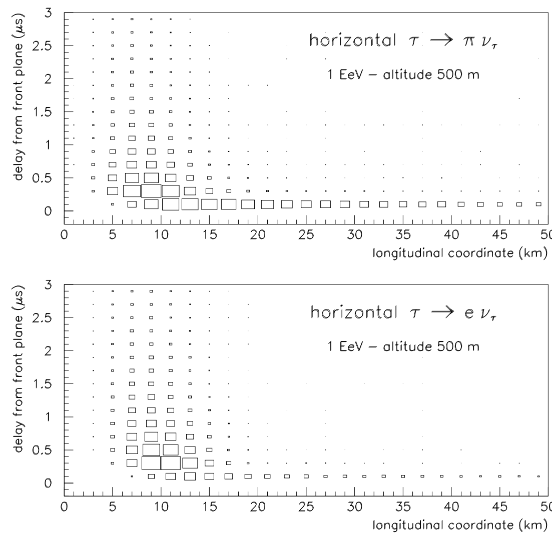

Figure 2. Time structure of horizontal showers induced by a τ of 1 EeV. The main difference is the importance of the muonic tail (concentrated at low delay times). 500m is the x altitude of the decay above the ground.

Fig. 2 shows the time structure of two showers induced by horizontal tau decays at low altitude. The areas of the boxes are proportional to the particle density and one can verify that the shower maximum occurs around 10 km after the decay point and that the "fat" part of the shower extends over 10 to 15 km. As mentioned above, after 20 km or so, only muons well in time with the shower front survive. This is illustrated in the shower generated by a hadronic decay of the tau which contains more muons than a shower from an electronic decay as one can see in Fig. 2

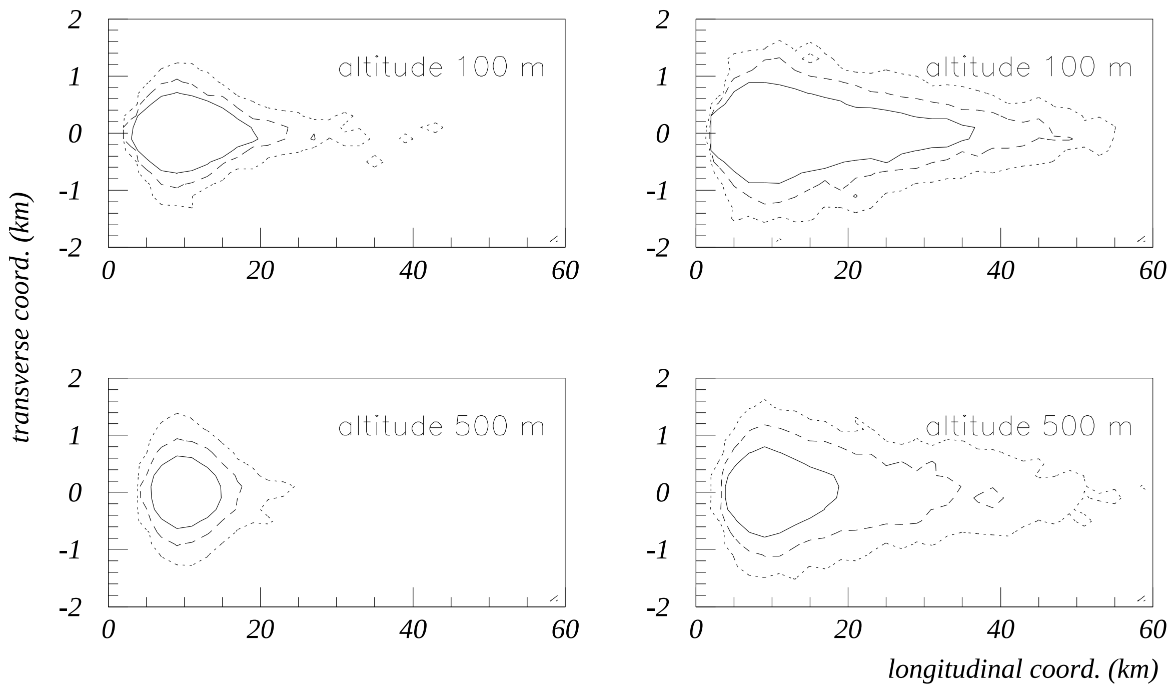

Figure 3. Ground spots of horizontal showers induced by a τ of 1 EeV. Lines are iso-density curves at the threshold of the tank local trigger (solid), at 0.3 (dashed) and at 0.1 (dotted). All of these data (even when below threshold) can be used from the global trigger generated by a set of local triggers. Left: τ decay into $e\nu_e\nu_\tau$; right: decay into $\pi\nu_\tau$

as the more important "in time" component at large distance.

Horizontal showers, due to their *longitudinal* extension and provided that their core is at sufficiently low altitude, may be seen in Auger at an energy much lower than the vertical shower threshold of 10 EeV. For example, a horizontal shower induced by a primary particle of 0.1 EeV has an effective radius larger than 300 m over 10 km; if its core is at 100 m above the ground, it may easily trigger 4 Čerenkov tanks or more. The extension of the shower core depends on the nature of the primaries. Due to the large range of the muonic component, charged hadrons give on average a larger footprint than electrons or neutral pions.

Fig. 3 shows examples of shower ground spots. The solid contours give the area where the particle density is above the local trigger threshold of the Čerenkov tanks. On average, an electronic tau decay at 500 meters would trigger 3 stations, a pionic decay at 500 meters 5 and at 100 meters more than 10.

3. Tau events simulation

3.1. Interactions in earth

A Monte-Carlo technique has been used to simulate the tau neutrino or charged lepton interactions and propagation inside the Earth. The lepton may interact several times through deep inelastic scattering, changing charge in most cases, or eventually decay, but, in all cases, a tau neutrino or charged lepton is present in the final state. Some energy is lost at each interaction, as well as continuously along the paths. However, in our energy range, the initial direction of the incoming neutrino is always conserved (Figure 4).

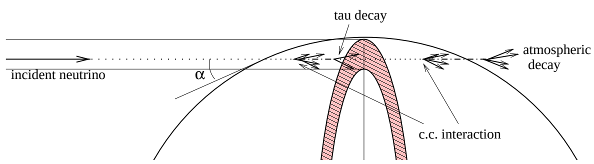

Figure 4. Chain of interactions producing an observable shower.

In our model, we assumed an isotropic incident flux of neutrinos, an homogeneous Earth with density 2.15 g/cm^3 [16], and a very high energy parameterization of the charged current (CC) cross section accurate to within 10% as given by the results of the CTEQ4-DIS parton distributions :

$$\sigma_{cc}^{\nu N} = 1.0 \left(\frac{E_\nu}{1\,EeV}\right)^{0.363} 10^{-32}\mathrm{cm}^2$$

A step-by-step method is used; at each step, the probabilities of different interactions and of the decay are evaluated as functions of the energy. Both CC and NC interactions are taken into account, with the cross section given above (and $\sigma_{nc} = 0.4\,\sigma_{cc}$) [15] ; the energy of the outgoing lepton is computed using a parametrization of the inelasticity at 1 EeV.

Energy losses have been calculated including Bremsstrahlung (BS) and Pair Production (PP) as well as Deep Inelastic Scattering (DIS). The energy loss model is of the form :

$$-\frac{dE}{dx} = a + b(E)E$$

where the second term is dominant above a few 100 GeV.

Contributions from BS and PP have been rescaled from the muon values given in reference [16] and [17], leading to $b = 0.08 \times 10^{-7}$ and $1.4 \times 10^{-7}\mathrm{g}^{-1}\mathrm{cm}^2$ respectively. We then obtained an attenuation length $L = (\rho \sum b)^{-1}$ of 31 km. DIS contributions rely on parameterization of the photo-nucleon cross sections as well as on the proper modelisation of the nucleon structure functions at very low x and/or very large Q^2. This subject being still tentative, we decided to use two different estimates, an energy independant contribution (DIS-low, $b = 10^{-7}\mathrm{g}^{-1}\mathrm{cm}^2$) rescaled from the muon behavior given in [17] and an energy dependant one (DIS-high, $b = 6\,E_{18}^{0.2} \times 10^{-7}\mathrm{g}^{-1}\mathrm{cm}^2$ which dominates energy losses above 10^{15}eV) as a parameterisation of the recent calculation from [18]. This later case gives an attenuation length as low as 6 km at 10^{18}eV strongly reducing the penetrating power of the tau.

The τ is assumed to decay according to the relative probabilities into one of the most frequent modes : e, μ, π, $\pi\pi^0$, $\pi\pi^+\pi^-$ and $\pi\pi^0\pi^0$, which cover 90% of the total decays. We simplified the kinematical distribution of the decay products, reproducing only the essential feature, namely the fraction of initial energy going into the electromagnetic shower and into the hadronic one[3]). A more accurate description would not modify our results as can be seen in Fig. 3 where the central ground region of a pure electromagnetic shower, although different, still compares with the hadronic one. The muons are considered to be unobservable. A possible effect of the longitudinal polarization of the tau was ignored.

Once a τ emerges from earth, and if a decay occurs within an altitude of 3 km above the ground, an atmospheric shower is simulated as described in Sec. 2.2. The detector response is then evaluated through a simulation (outlined below) of the interactions of incident particles in water.

Interactions in the mountains surrounding the detector were also simulated, using a detailed description of the relief. Their contribution was found to be much less than the material below sea level, whatever the energy. On the other hand we did not account for the lower density in Pacific Ocean, 250 km West from the southern site. The overall correction is less than 10 %.

3.2. Detector response

The set of weighted ground particles in a "sampling region" around each station is used to regenerate a set of particles entering the tank, statistically reproducing all significant characteristics of the incident flux : global normalization of the

[3]Note that at 1 EeV the decay length of a π^0 is 200 m, therefore comparable to the interaction length in air (750m)

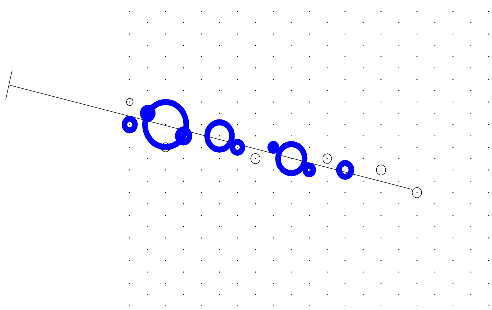

Figure 5. Simulation of the ground trace left by a τ decay shower as produced by a $5{\times}10^{17}$eV tau neutrino. Each thick circle represents a triggered station with a surface proportional to the Cerenkov signal. The τ shower had an energy of $3.63{\times}10^{17}$eV and decayed 390 meters above the ground. In this particular exemple energy deposition in triggered tanks ranges from 4 to almost 100 *vem*.

different particles, distribution in energy and direction.

Then a simplified simulation is performed for interactions (cascade of Compton scattering and pair production for photons, energy loss for charged particles) and Čerenkov emission in the water. The production of Čerenkov photons and their propagation in the tank is performed until they hit a PMT or are absorbed in the water or in the tank walls. The PMT response is assumed to be proportional to the amount of light emitted. This is a good approximation in most cases, in particular for the sum over the three PMTs collecting the light from the tank.

The level of the local trigger (one tank) is set to 4 *vem* (vertical equivalent muons), and a global trigger is built if at least 4 stations are locally triggered within 20 μs with a relatively compact topology. For exemple at least two stations must be within 3 km from a “central” one, and an additional one within 6 km. If needed, some long-shaped configurations with nearly aligned stations and the right time spacing could be added to the global trigger processor. These allow to a gain of up to 50 % in the acceptance at energies between 0.1 and 0.3 EeV. However, we did not include these additions in this study.

Fig. 5 shows a simulation of the ground trace of a tau, produced by a $5{\times}10^{17}$eV neutrino, as sampled by the Auger stations. The signal is clearly visible and 10 stations pass the 4 *vem* trigger requirement (thick circles).

The probability to detect a shower with a given visible energy depends essentially on the altitude of the core at the maximal lateral development. It is not very sensitive to the exact definition of the local trigger threshold nor to the global configuration. For example, detecting all events with 3 locally triggered stations would not increase sensibly the rate, except on the edges of the acceptance below a few times 0.1 EeV. This is illustrated on Fig.6, where the equivalent area for detecting a shower has been plotted for various trigger conditions : triangles 3 stations, squares 4 stations and circles 4 stations plus the above condition on the global configuration.

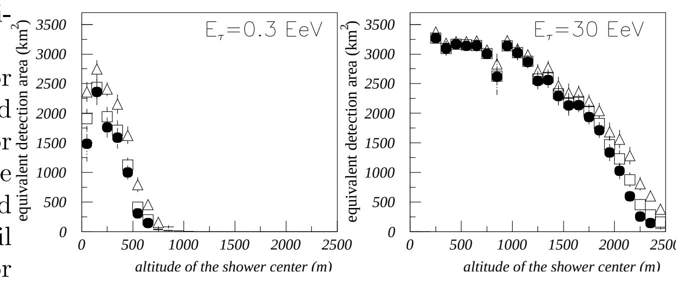

Figure 6. Equivalent detection area of tau showers averaged over all decay channels versus the shower center (defined 10 km after the decay point) altitude. Triangles : 3 stations global trigger, squares 4 stations, circles 4 stations and the compact topology restriction.

3.3. Reconstruction

The direction of origin may be estimated from the times of arrival of the shower front on the stations, which is, as a first approximation, a plane moving at speed c. The precision on the azimuthal angle φ is of the order of 1 deg, and could be improved by taking into account the front curvature and by weighting each station contribution

according to its integrated amplitude.

As a horizontal array is only sensitive to $\sin\theta$ the zenith angle θ is quite difficult to obtain precisely. However, taus are all produced with $|\theta - 90| < 5$ deg. Therefore one can isolate them from the standard horizontal neutrino shower as can be seen on Fig. 7.

The reconstruction of the energy E_i of the incident neutrino is much more delicate :

- The energy E_τ of the emerging tau may be much less than E_i, in particular for $E_i \gg 1$ EeV, where many intermediate interactions may have occurred reducing E_τ to a few 0.1 EeV. As θ is not well known, it is difficult to evaluate even an order of magnitude of the energy loss.

- An arbitrary fraction of E_τ goes into neutrinos and will not be visible while the decay type will influence the hadronic to electromagnetic ratio of the decay products. This may be corrected for only if the tail of the shower is visible on the ground.

- The estimation of the shower energy depends strongly on the altitude of the shower core which is *a priori* unknown. If many stations are hit, there is a hope to evaluate it from the transverse distribution.

Given these difficulties, we can predict the rate of events knowing the energy spectrum of the original neutrinos. The inverse will be difficult.

A careful statistical analysis of all observable characteristics such as tank multiplicity, longitudinal and transverse profile of the ground spot and time structure will certainly give additional information on the original spectrum. We also beleive that for events where a arge number of tanks are struck we can obtain an estimate of the neutrino energy but those studies need to be done. Of course, the hybrid reconstruction (involving both the ground array and the fluorescence detector of Auger) will be extremely valuable to remove some ambiguities (zenith angle, visible energy), but such "golden" events are expected to be less than 10% of the total event rate.

3.4. Evaluation of the acceptance

The rate of observable events on a given surface A (surface covered by the Ground Array) is simply the rate over the whole earth, multiplied by $A/(4\pi R_T^2)$, where R_T is the radius of the earth. This rate may be evaluated from a parallel flux crossing the earth section (πR_T^2) as the integration over the solid angle just gives an additional factor of 4π.

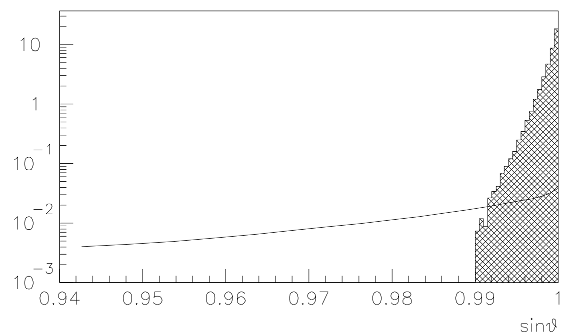

Figure 7. *Sinθ* distribution of accepted events. Solid line : neutrino interaction in the atmosphere, filled area : tau neutrino interaction in the ground. The normalization between the two curves (1:20) roughly corresponds to $\nu_\mu \leftrightarrow \nu_\tau$ oscillations with full mixing and an E^{-2} flux. The RMS on the reconstructed *sinθ* is at most 0.005.

A tau emerging with an angle α over the horizon greater than $\alpha_m = 0.3$ rad has no chance of producing an observable shower at ground level. Therefore we only simulated incident neutrinos close to the earth surface for which $\alpha \leq 0.3$ rad (hatched area on Fig.4). For various incident energies, $N_{sim} = 10^6$ neutrinos were simulated and the complete history up to the trigger was followed, giving the total number N_{acc} of accepted events.

The apperture at a given energy may then be defined as:

$$\begin{aligned} A_{\text{eff}} &= 4\pi\ \pi R_T^2 \sin^2\alpha_m\ \frac{A}{4\pi R_T^2}\ \frac{N_{\text{acc}}}{N_{\text{sim}}} \\ &= \pi A \sin^2\alpha_m\ \frac{N_{\text{acc}}}{N_{\text{sim}}} \end{aligned}$$

and the rate of events (integrated over the solid angle) coming from neutrinos of energy between E_1 and E_2 as :

$$\frac{dN_{\rm acc}}{dt} = \int_{E_1}^{E_2} f(E)\, A_{\rm eff}(E)\, dE$$

where $f(E)$ is the incident flux.

3.5. Analytic estimation

A simple analytic computation of the acceptance is easy if :

1. the energy loss of tau leptons in the earth can be neglected;
2. only events with a unique interaction (single bang) in earth are considered;
3. the tau is assumed to carry always the same fraction (80%) of the neutrino energy;
4. a simple geometric condition on the position of the tau decay can model the detection condition.

From our full Monte-Carlo studies of the probability of detection of a tau shower in Auger, given its energy, zenith angle, and altitude of decay we found that a reasonable description of the largest detection altitude of the shower maximum was given by :

$$h_m = 1000 + 500 \times \log(E_{18})$$

where h_m is the altitude in meters of the shower maximum.

A more complete estimation can be done taking into account multiple interaction in earth (multi-bang events). Taking into account multi-bang events increases considerably the acceptance at larger angles whatever the energy.

Fig. 8 shows the probability of producing and detecting a tau shower as a function of its zenith angle. The contribution of the various multi-bang events can be seen.

The acceptance can then be computed and compared with our full Monte-Carlo results (see Fig 9). Differences come mainly from the approximations of the geometrical detection condition and from the absence of energy loss in our analytical calculation.

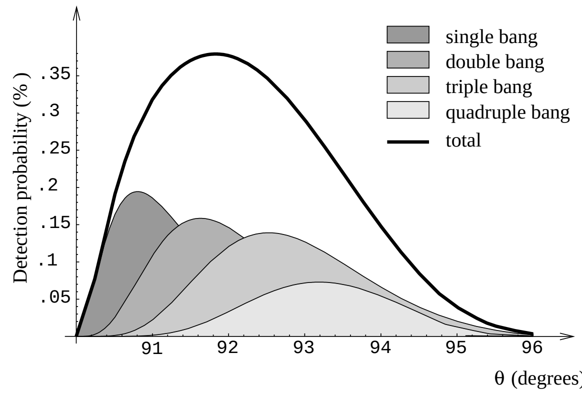

Figure 8. Probability of detection of a tau shower for a 3.10^{18}eV neutrino hitting the Auger array as a function of zenith angle.

4. Expected event rate

4.1. Acceptance

The acceptance for ν_τ interaction in the rocks surrounding the Auger array is shown on Fig.9. It may be represented either by the "effective cross section" defined in Sec. 3.4, or, by introducing the event rate per decade :

$$\begin{aligned} I_{10}(E) &= \lim_{\epsilon\to 0} \frac{\int_{E-\epsilon}^{E+\epsilon} f(e) A_{eff}(e)\, de}{\log_{10}\left(\frac{E+\epsilon}{E-\epsilon}\right)} \\ &= \ln 10\, E\, f(E)\, A_{eff}(E) \end{aligned}$$

With this definition, one can directly obtain the number of events detected per year measuring the area under the curve $I_{10}(E)$ on a $I_{10}(E)$ versus log E plot as shown on Fig. 10.

We defined the Auger flux sensitivity as the neutrino flux giving at least one observed event per decade of energy every year i.e. for which $I_{10}(E) = 1$. This sensitivity is shown on Fig. 11 together with the expected fluxes from a model calculation by Protheroe [19]. All predicted fluxes are ν_μ fluxes, in the full mixing hypothesis ν_τ fluxes are half of those. The limits from atmospheric neutrino interaction formerly calculated in [10] and from our present calculation of ν_τ interactions in the rocks are shown.

For standard neutrino interactions in the atmo-

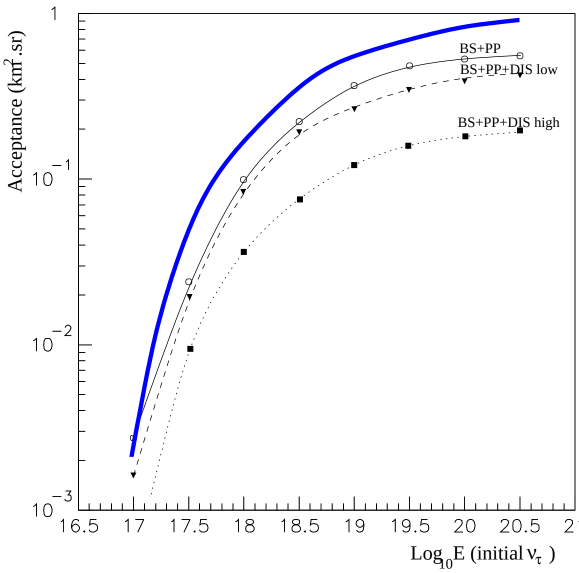

Figure 9. Auger array effective aperture to ν_τ. Various continuous energy loss models are presented. BS : bremmstrahlung, PP pair production, DIS deep inelastic scattering. The thick solid line is our analytical calculation without energy loss.

sphere, each site of the Auger observatory reaches 10 km^3 water equivalent (w.e.) of target mass at 1 EeV, and only the models classified as speculative by Protheroe [19] are expected to yield a detectable signal. However, for tau induced showers the target mass is increased by a factor of about 30 at 1 EeV, allowing for a detectable signal even for the lowest expected fluxes. The expected number of events per year from various UHECR production models and from the GZK[4] neutrinos (a very low but almost certain flux) are presented in Table 1.

The data in the table demonstrate the capability of the Auger detector to probe the GZK neutrino flux. This is a crucial test as most acceleration mechanisms of protons in cosmologically distributed sources as well as top-down models will produce a neutrino flux at least equal to this one.

Table 1
Expected number of events per year for the source models presented in Fig. 11 and various DIS contributions to continuous energy losses.

DIS	AGN-1	TD	GRB	GZK	AGN-2
none	27.0	2.3	0.5	1.7	2.9
low	24.0	1.8	0.4	1.5	2.5
high	10.0	0.8	0.2	0.6	1.1

5. Conclusions

The Auger observatories are found to have an optimal geometry for the detection of ν_τ interaction in earth in the $0.1 - 100$ EeV energy range (the GZK range). Indeed, above 10^{17}eV the earth

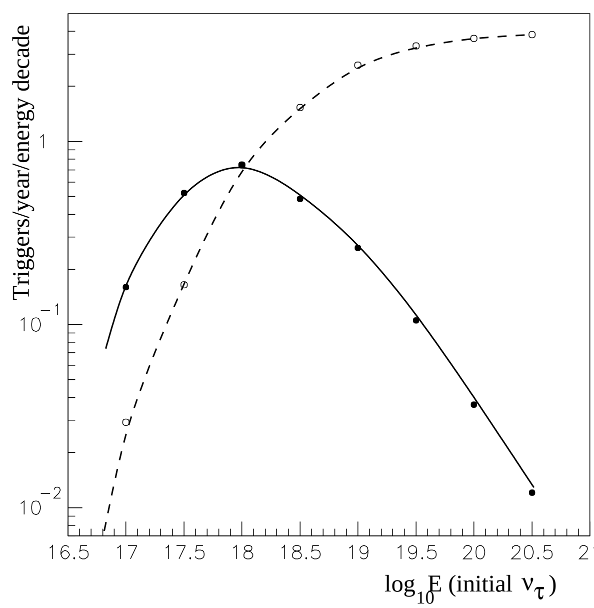

Figure 10. The event rate per decade for BS+PP energy loss only.
solid line $f(E) = 3.1\, E_{18}^{-2}$ EeV^{-1}km^{-2}y^{-1}sr^{-1};
dashed line $f(E) = 3.1\, E_{18}^{-1}$ EeV^{-1}km^{-2}y^{-1}sr^{-1}.
(3.1 EeV km^{-2}y^{-1} $\equiv 10^{-8}$ GeV cm^{-2}s^{-1}).

[4]One should note that the GZK neutrino model that we have taken from [19] is almost one order of magnitude lower than the prediction given in [20] therefore we feel quite confident that the Auger observatory will observe a few ν_τ candidates if the $\nu_\mu \leftrightarrow \nu_\tau$ oscillation results are confirmed.

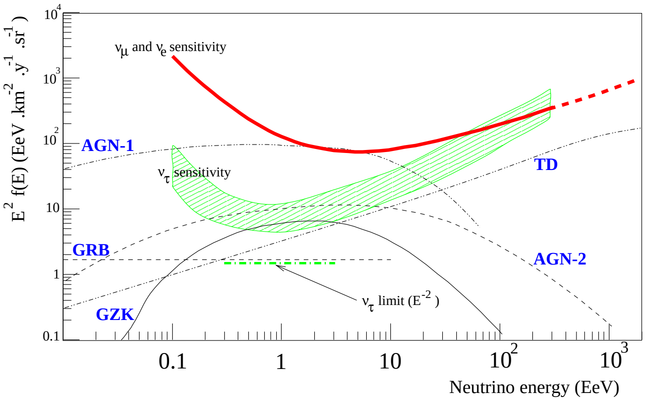

Figure 11. Muon or tau neutrino and anti-neutrino fluxes from various sources in the full mixing hypothesys, taken from [19] (and divided by 2). Dotted lines are speculative fluxes, dashed probable and solid certain. The thick solid line and the hatched area represent the Auger sensitivity defined by $I_{10}(E) = 1$, i.e. one event per year and per decade. Top line for horizontal shower from ν_e and ν_μ interactions in the atmosphere hatched area for tau induced showers under strong DIS loss (top of the area) or no DIS loss (bottom). Any flux lying above those curves for at least one decade will give more than one events per year in Auger. We also plotted the 90% C.L. limit (background free detection) for an E^{-2} flux between 0.3 and 3 EeV that Auger could acheive after five years.

is not transparent to neutrinos and for tau or muon neutrinos successive charged/neutral current interactions will degrade the energy below 10^{16}eV, mixing the high energy signal with the more standard and far more numerous low energy one. Therefore a maximum of a few 100 km of rocks should intersect the neutrino trajectory to limit the number of interactions and allow a high energy lepton (above 10^{17}eV) to escape. Only nearly horizontal neutrinos interacting in mountains or in the top few kilometers of the Earth fulfill this requirement.

At a few tens of EeV, the tau decay length is over 1000 km and the probability of a decay inside the field of view of current or foreseen detectors becomes very small. Therefore, only the energy range $0.1 - 10$ EeV is truly visible. At these relatively "low" energies the fluorescence signal is rather small and will be difficult to see from far away (a few tens of km), a necessary condition to have enough acceptance for observing a few events a year.

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